FISHES OF SABKHA-RELATED HABITATS

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Abstract
The taxonomy and ecology of fish species known to live in sabkha-related habitats is poorly known. An annotated account of seven species is provided and additional fish taxa that potentially occur are listed. There are no fish species known to date that are found exclusively in sabkha habitats. The species composition essentially depends on colonisation with marine species of the adjacent ocean. In addition amphidromous and very few freshwater fishes are potentially encountered in sabkhat. The fish species can be classified ecologically as transients represented by tidal and seasonal visitors or residents represented by true and partial residents. Only *Lebias dispar* seems to be a true resident. Migratory and vagrant species form the largest proportion of the sabkha fish community. To live under the environmental conditions of sabkhat presents unique problems to fishes. The disadvantages are apparently outweighed, at least for a limited suite of preadapted species, by a comparatively comfortable situation as far as competition for food and space, and predation are concerned. The present review suggests that sabkha fish are more significant in terms of number of species and individuals, and hence of greater ecological importance, than previously expected.

INTRODUCTION

Sabkha-related aquatic habitats are characterised by environmental factors which strongly fluctuate and temporarily reach extreme values, e.g. temperature, salinity, oxygen content, pH, nutrient content and several others. The taxonomy and ecology of fish species known to live under these environmental conditions around the

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Arabian peninsula is poorly known. In spite of the large area of sabkhat in the region and the apparently small number of species in question, ichthyological literature specifically on sabkhat is scarce. This paucity of data is, firstly, due to a lack of systematic collecting and survey work. Secondly, species recorded from related aquatic or semi-aquatic habitats have not been referred to as "sabkha fishes" but as inhabitants of e.g. tidal creeks or lagoons. The sabkha ecosystem definitions previously in use have not been 'aquatic' enough to promote the study of fishes since subsurface, interstitial water was considered the main water body of a sabkha environment in sensu strictu. The definitions set by this book, especially for coastal and supralittoral sabkhat shape the delimitations towards aquatic habitats linked to sabkhat that form permanent or ephemeral indentations of marine, or freshwater origin. On this assumption the aquatic realm merits its consideration as an integral part of certain sabkhat. Still, few species of fish have been hitherto recognised.

In essence this chapter represents a literature review, largely based upon studies carried out in the Gulf region. Due to the lack of studies specifically on sabkhat references have been used dealing with "restricted environments" which are spatially and ecologically linked to sabkhat. Beside a few true records from these habitats the species considered have been extrapolated from the suite of littoral and coastal migratory fishes which are known to thrive in tidal creeks, tide channels, mangrove swamps and mudflats in the area. Important contributions to the knowledge of restricted coastal environments of the Arabian Gulf were made by Evans et al. (1973), Hughes Clarke & Keij (1973), Basson et al. (1977) and MEPA/IUCN (1989). Only scattered data on fishes are included in these publications. A treatise of the intertidal fishes of Kuwait was provided by Clayton & Seedo (1986). A study of the fishes of the coastal lagoons of Dhofar, Oman, was presented by Fouda (1995). Comprehensive accounts of the fishes of the Gulf, or of certain parts of it, were published by Blegvad (1944), Al-Baharna (1986), Kuronuma & Abe (1986), and Carpenter et al. (1997), of Oman by Randall (1995), and of the Red Sea by Goren & Dor (1994).

As with faunistic studies, the ecological importance of sabkha habitats for fishes has also received little attention from researchers. First, owing to the paucity of original data, information about the ecology and habitat demands of the above considered species were compiled from Carpenter et al. (1997), Randall (1995) and FishBase (Froese & Pauly 1999). Second, ecological strategies of salt marsh fishes identified from other regions (Moyle & Cech 1982) were compared to the available data, then used to interpolate a picture of some order of probability.

The nomenclature used herein follows Eschmeyer (1998), in accordance with the International Code of Zoological Nomenclature (1999). The authors trust that the bulk of standard literature dealing with coastal wetland, mangal and estuarine ecology is being referred to elsewhere in this volume. The fossil record of fishes petrified during sedimentation processes of ancient sabkhat is not treated in this contribution. A general review of the fossil fishes of the intertidal zone can be found in Schultze (1999).

SPECIES ACCOUNT

The number of fish species present in a salt marsh is typically fewer than 15 (Moyle & Cech 1982). This figure refers to salt marshes in higher latitudes. The definite number that occurs at any time in our area of concern is not known. An annotated account of seven species is provided which have been so far reported from sabkha-related environments. In addition a list of fish species which potentially occur is given below. The data on habitat and biology, size and distribution ranges were compiled from Carpenter et al. (1997), Fischer et al. (1990), FishBase (Froese & Pauly 1999), Lieske & Myers (1994), Randall (1995), Whitehead (1985) and Wildekamp et al. (1986), unless stated otherwise.

Abbreviations: SL = standard length; TL = total length

Family **Clupeidae** - Herrings, sardinellas, sardines, and shads
Sardinella sindensis (Day, 1878)
Common name: Sind sardinella (English) - Abed or Uma (Arabic, Oman), Mashineh or Moomagh (Arabic: Bahrain, Iraq, Kuwait, Qatar, Saudi Arabia, UAE), 'Um (Arabic).
Habitat & Biology: Saltwater, pelagic. Schooling in coastal waters. Marketed fresh and dried-salted.
Size: Commonly to 14 cm SL, maximum to 17-20 cm SL.
Range: Western Indian Ocean; Arabian Sea, from Gulf of Aden to the Arabian Gulf and Bombay, also reported from Mauritius.
Remark: Additional clupeids with similar life habits occur in the area and may therefore be encountered in sabkhat.

Family **Cyprinodontidae** – Pupfishes, killifishes
Lebias dispar dispar Rüppell, 1829
Common name: Arabian killifish / pupfish (English) - Afty (Arabic, Qatar), Harsun (Arabic).
Habitat & Biology: Demersal, lives and reproduces under freshwater, brackish and marine conditions. Survives high salinities and temperatures. Occurs in coastal zones near the surface, usually found in estuaries, but also has been taken in shallow reef areas. Found in inland pools with hypersaline to fresh water. A schooling, omnivorous species.
Size: Commonly to 5 cm TL, males reported to 8 cm, females to 6 cm.
Range: Indian Ocean, Red Sea, Arabian Gulf, Dead Sea; landlocked populations in Saudi Arabia, Iran, Siwa Oasis, western Egypt. Immigrant via the Suez Canal into the Mediterranean.
Remark: The genus name *Lebias* has priority over its widely used synonym *Aphanius* (Lazara 1995). In the United Arab Emirates, according to Gary Feulner (pers. comm.), "it is probably the single most abundant fish in the Ras al-Khaimah and Umm al-Qaiwain mangrove areas discovered to date". Probably the species with the greatest abilities to cope with the harsh and fluctuating environmental conditions of sabkha-related habitats. Several congeners are recorded from the area and are expected to occur in sabkhat, e.g. *Lebias stiassnyae* Getahun & Lazara, 2001 has recently been described from the hypersaline Lake Afdera, Ethiopia.

Family **Sparidae** - Porgies and seabreams

Argyrops spinifer (Forsskål, 1775)

Common name: King soldierbream (English) - Andaq (Arabic, Qatar), Kofar or Kofer (Arabic, UAE), Cophra, Da'ara, Kawfar or Rababa (Arabic, Oman), Kufar (Arabic).

Habitat & Biology: Saltwater, demersal. Only the young fish occur in very shallow waters of sheltered bays and lagoons; larger individuals in deeper water, being most common between 5 and 100 m. Inhabits a wide range of bottoms, but especially over mud or sand substrata. Hunting macrofauna, mainly benthic invertebrates such as molluscs. Important as foodfish.

Size: Commonly to 30 cm TL (Bauchot & Smith 1984), maximum to 70 cm TL.

Range: Indo-West Pacific; from Red Sea, Arabian Gulf, South Africa and East Africa to the Indo-Malayan archipelago and northern Australia.

Remark: The species has frequently been confused with *Argyrops filamentosus* (Valenciennes, 1830).

Family **Serranidae** – Groupers and seabasses

Epinephelus coioides (Hamilton, 1822)

Common name: Orange-spotted grouper (English) - Hamoor (Arabic, UAE), Hamour (Arabic, Qatar), Balool = juvenile (Arabic).

Habitat & Biology: Marine and brackish water, reef-associated. Found along continental and large island shores; often occurs in brackish areas, also inhabits turbid coastal reefs down to depths of 100 m. Juveniles are common in shallow waters of estuaries and mangal biotopes over soft sediments. Hunting macrofauna, mostly small fishes, shrimps, and crabs. Important and highly prized food fish.

Size: Up to 100 cm SL (Kottelat et al. 1993).

Range: Indo-West Pacific; from the Arabian Gulf and the Red Sea south to Natal, South Africa and east to the western Pacific, including Australia. Has invaded the Mediterranean as Lessepsian migrant.

Remark: The species has previously been misidentified as *E. malabaricus* (Bloch & Schneider, 1801) or *E. tauvina* (Forsskål, 1775) in the Gulf, both of which do not occur there.

Family **Terapontidae** – Terapons, grunters, or tigerfishes

Terapon jarbua (Forsskål, 1775)

Common name: Jarbua terapon, thornfish or crescent perch (English) – Baam, Jimjam, Yanam (Arabic, Oman), Yamyam (Arabic, U.A.E.), Dheeb (Arabic).

Habitat & Biology: Saltwater, freshwater, demersal, catadromous. Found in schools in shallow waters above soft sediment bottoms. Enters estuaries and rivers. Spawns in the sea and juveniles migrate into fresh water. Omnivorous. Capable of producing sound.

Size: Commonly around 25 cm SL, maximum reported to 33 cm.

Range: Indo-Pacific; Red Sea to Southeast Asia, and western Pacific.

Family **Gerreidae** – Silver-biddies and mojarras

Gerres oyena (Forsskål, 1775)

Common name: Common silver-biddy or blacktip mojarra (English) - Badhah (Arabic, Qatar), Bedhah (Arabic, UAE), Badha or Mussalakh (Arabic, Oman), Badh ar-rayash (adult), Musallakh (juvenile) (Arabic).

Habitat & Biology: Brackish, saltwater, demersal. Commonly found in shallow water, lagoons, estuaries and mangrove sloughs. Occurs singly or in groups over shallow sandy areas (Sano et al. 1984). Feeds on small organisms, thriving in sandy substrates. Marketed fresh or used for fishmeal.

Size: Commonly to 15 cm SL, maximum to 30 cm (Roux 1986), or to about 20 cm respectively.

Range: Indo-Pacific; Red Sea, Arabian Gulf, to the south-eastern coasts of India and East Africa, extending to the western Pacific.

Family **Mugilidae** - Mullets
Liza subviridis (Valenciennes, 1836)
Common name: Greenback mullet (English) - Araby or Beyah (Arabic, Saudi Arabia), Anubah, Biyah, Gawafa or Gutarana (Arabic, Oman)
Habitat & Biology: Brackish, saltwater, demersal. Forms schools in shallow coastal waters and enters lagoons, estuaries, and freshwater to feed, juveniles may enter rice fields and mangroves. Feeds on small algae, diatoms and benthic detrital material taken in with sand and mud; fry take zooplankton, diatoms, detrital material and inorganic sediment. Spawning occurs at sea. Marketed fresh and salted.
Size: Commonly to 25 cm SL, maximum to 30 cm SL.
Range: Indo-Pacific, Red Sea, Arabian Gulf to western Pacific, south to Natal, South Africa.
Remark: Listed as *Chelon subviridis* in Randall (1995). Part of the type series originates from the River Ganges. A frequently used synonym is *Mugil dussumieri* Valenciennes. Several species of the family Mugilidae with similar life habits occur in the area and may therefore by recorded from sabkhat.

Additional fish taxa that potentially occur in sabkhat are listed below. The selection is based on physiological abilities, habits, life histories, and on literature records from habitats which occur in association with sabkhat, such as tropical coastal lagoons (Yáñez-Arancibia et al. 1994, Fouda 1995), and marsas (or mersas = shallow embayments) and mangrove swamps (Khalil 1994, Ormond & Edwards 1987, Por et al. 1977). Taxa marked by an asterisk are exclusively freshwater fishes.

Dasyatidae
Elopiidae
Elops machnata (Forsskål, 1775)
Megalopidae
Megalops cyprinoides (Broussonet, 1782)
Ophichthidae
Lamnostoma orientalis (McClelland, 1844)
Muraenichthys schultzei Bleeker, 1857
Clupeidae
Nematalosa nasus (Bloch, 1795)
Thryssa hamiltonii (Gray, 1835)
Engraulididae
Chanidae
Chanos chanos (Forsskål, 1775)
Cyprinidae*
various species
Heteropneustidae*
Heteropneustes fossilis (Bloch, 1801)
Ariidae
Arius tenuispinis Day, 1877
Plotosidae
Batrachoididae
Atherinidae
Belonidae
Tylosurus crocodilus (Peron & Lesueur, 1821)
Hemiramphidae
Hemiramphus far (Forsskål, 1775)
Cyprinodontidae
Lebias sophiae (Heckel in Russegger, 1846)
Lebias stiassnyae Getahun & Lazara, 2001
Scorpaenidae
Pseudosynanceia melanostigma Day, 1875
Platycephalidae
Platycephalus indicus (Linnaeus, 1758)
Ambassidae
Ambassis gymnocephalus (Lacepède, 1802)
Terapontidae
Pelates quadrilineatus (Bloch, 1790)
Terapon puta (Cuvier, 1829)
Terapon theraps (Cuvier, 1829)
Silliganidae
Sillago sihama (Forsskål, 1775)
Carangidae
Caranx spp.
Trachinotus spp.
Monodactylidae
Monodactylus argenteus (Linnaeus, 1758)
Leiognathidae
Leiognathus decorus De Vis, 1884
Gerreidae
Gerres spp.
Lutjanidae
Haemulidae
Sparidae
Petrus belayewi Hora & Misra, 1943

Nemipteridae
Polynemidae
Sciaenidae
Mullidae
Pomacanthidae
Pomacanthus maculosus (Forsskål, 1775)
Mugilidae
Liza abu (Heckel, 1843)
Liza klunzingeri (Day, 1888)
Pinguipedidae
Trichonotidae
Blenniidae
Omobranchus spp.
Gobiidae
Apocryptodon madurensis (Bleeker, 1849)
Aulopareia cyanomos (Bleeker, 1849)
Boleophthalmus spp.
Periophthalmus barbarus (Linnaeus, 1766)
Periophthalmus waltoni Koumans, 1941
Scartelaos histophorus (Valenciennes, 1837)
Scartelaos tenius (Day, 1876)
Valenciennea persica Hoese & Larson, 1994
Microdesmidae
Ephippidae
Platax spp.
Scatophagidae
Scatophagus argus (Linnaeus, 1766)
Siganidae
Siganus spp.
Soleidae
Euryglossa orientalis (Bloch & Schneider, 1801)
Paralichthyidae
Pseudorhombus sp.
Triacanthidae
Triacanthus biaculeatus (Bloch, 1786)
Tetraodontidae
Lagocephalus spp.
Torquigener spp.

ECOLOGY

At the interface between aquatic and terrestrial ecosystems, coastal and supralittoral sabkhat are among the most demanding habitats for higher organisms, in particular for fishes.

Water

Water is a critical requirement for fishes; the vast majority of fishes are fully aquatic and only a few have behavioural and physiological adaptations for drought or limited exposure to air. In the tropics and subtropics e.g. certain gobioids and blenniids are able to survive out of water for a limited time. For those species which are unable to do so the exploration of sabkha habitats poses the problem of how to not get accidentally trapped under unfavourable conditions, whether caused by the receding tides or by evaporation. There are no fish species known to date that are found exclusively in sabkha habitats. The species composition essentially depends on colonisation with marine species from coastal and littoral habitats of the adjacent ocean, or perhaps rarely with species of freshwater origin.

The tidal regimes of the Gulf are very complex, their periodicities vary greatly over the length of the area, and with the seasons. The surfaces of the lower salt marshes flood and drain, and coupled with the tidal regimes, this causes the littoral fringe periodically to expand far into the coastal wetlands. The range of the actual tidal amplitudes between the mean high and the mean low water can be very wide. For Kuwait, Jones (1986) reported a vertical amplitude of 3-4 m in the north to less than 2 m in the south. Horizontally the tidal amplitudes reach up to 2 km in certain areas (Wright et al. 1990). In addition, at times of maximum and spring tides also the supratidal sabkhat become temporarily flooded as well. This gives rise to a wealth of ephemeral aquatic habitats, as well as to permanent aquifers like drainage channels and tidal creeks (Gibson 1999).

In classifying the fish species ecologically, one needs to distinguish first between temporary immigrants, say transients, which are visitors or irregular "strays", compared to a very few species which are resident at least during a certain time of their life. Transients are species for which the intertidal provides nursery areas for juveniles or feedings grounds for subtidal species on foraging excursions. Residents are defined as species which spend their entire lives or at least a major part of it interacting with other sabkha organisms (Gibson 1969), and which show only limited horizontal movement with the tidal fluctuations. An elaborate classification has been devised by Moyle & Cech (1982) which divides the transients into tidal visitors, e.g. sciaenids, flounders, and halfbeaks, and seasonal visitors, e.g. drums, anchovies, mullets, and mojarras. The former move into the marshes at high tides in order to feed, the latter use the salt marshes as spawning or nursery areas, or as seasonal refuges from predators. Among the residents these authors distinguish between true residents e.g. killifishes, which complete their entire life cycle on the salt marshes and partial residents e.g. silversides, which occur only as juveniles. There is certainly no sharp delimitation between partial residents and seasonal visitors. Gundermann & Popper (1984) divided mangrove fishes into three categories: 1) true residents, 2) closely associated species, and 3) loosely associated species (Khalil 1994). Another grouping has been suggested by Peterson & Turner (1994), according to the extent the species use the marsh surface. Based upon Louisiana salt marsh fishes, they separate: 1) interior marsh residents that remain in flooded depressions on the marsh surface at low tide, 2) interior marsh users that move onto the marsh at high tide but return to the edge of the creeks at low tide, 3) edge mark users, resident and transient species that occupy only the margins of marshes at the edge of creeks, and 4) a group of subtidal species that do not move onto the flooded marsh at all. Several studies of salt marsh fishes and their patterns of tidal migrations are available, mainly from temperate and boreal regions, but nothing has been published yet from our area of concern.

Active emergence, terrestrial shuttling to and from the waterline, aestivation in burrows and wet pockets, as well as the ability to breathe air on occasion are responses to varying or adverse environmental conditions (Martin & Bridges 1999). The emerging species have been classified into skippers, tide pool emergers, and remainers by Martin according to the extent of a species' behavioural tendency to actively leave the water. Beside drought, emergence behaviour is primarily triggered by other physical factors like temperature, salinity, oxygen content or pH. If aquatic conditions become inhospitable the emergence strategies no doubt increase a species' fitness in the stressful sabkha environment. Such amphibious specialisations are generally found among less motile groups of fishes which are preadapted to upper littoral habitats e.g. the various species of rock and mudskippers, or toadfishes. At present only *Lebias dispar* seems to be a true resident in sabkhat. Among over 30 species recorded from Sudanese mangals (Khalil 1994) only *L. dispar*, *Gerres oyena* and some undetermined gobiids proved to complete their life cycles in the mangroves. Gobiid mudskippers of the genus *Periophthalmus* live in the mangroves, and on mud flats where they are active at low tides. This genus has been reported to occur sympatrically with other mudskippers of the genera *Boleophthalmus* and *Scartelaos* in the region (Clayton & Vaughan 1982, Zander et al. 1999). Intertidal catch studies (Wright et al. 1990) indicate that *Periophthalmus* species stay in their burrows during the high-tides. The genera *Boleophthalmus* and *Scartelaos* are more closely associated with the upper littoral below the *Periophthalmus* zone, but are also found on regularly inundated mudflats associated with sabkhat.

Still, any of these adaptations remains rather limited in terms of survival time gained under conditions of desiccation and exposure. The highly specialised species of the African lungfish family Protopteridae, which hibernate underground, enveloped in clay burrows or mucus cocoons, do actually occur in African Red Sea countries, but are confined to freshwater and therefore are unlikely to be found in sabkhat.

The prevalent suite of species suggests that migratory and vagrant species which are not restricted to certain benthic habitats form the superior proportion of the sabkha fish community. They are capable of rapidly colonising ephemeral aquatic habitats on occasion. They move in and out with the tides in search of food, and respond to unfavourable conditions by following the receding waterline or by leaving the zone completely. For several species it has been shown that they follow high flood-waters, e.g. *Liza klunzingeri* and *Leiognathus decorus* (Abou-Seedo et al. 1990). They belong to a suite of 76 species in 36 families which are frequently caught in intertidal fish traps in Kuwait (Abou-Seedo 1992, Gibson 1999).

Environment & habitat

Aquatic sabkha habitats produce extreme environments for its inhabitants which have to face the risk of dehydration during periods of emersion, and extreme values and severe changes of temperature, salinity, oxygen content, pH and other parameters caused by evaporation or precipitation. Thus, to maintain respiration, osmo and acid-base regulation, excretion and other metabolic processes presents unique problems to fishes and restrict sabkha environments to a small but select suite of preadapted species. However, it is not implicit that the adverse factors necessarily render the habitats unsuitable for the establishment of robust and productive communities. Restricted environments are often rich in number of individuals made up by relatively few species. Certain species of micro-algae, foraminifera, molluscs, annelid worms, crustaceans, echinoderms, and also fishes have adapted to hypersaline conditions and may happen to occur in large populations in sabkha-related aquatic habitats. Still, the diversity undoubtedly decreases as environmental factors like salinity, temperature, oxygen depletion and pH increase. This then usually coincides with a reduced interchange of the water body concerned and the adjacent ocean.

The restricted coastal environments of the Gulf were classified by several studies (Hughes Clarke & Keij 1973, Basson et al. 1977, MEPA/IUCN 1989) into ecological subdivisions, according to the prevalent salinities, general biological characteristics and biota recognised including species of fish.

The "normal marine environment" - salinities of up to 50 ppt: Metahaline biotopes with a similar or slightly higher salinity than the adjacent ocean, like lagoons, mangrove swamps and tidal channels; housing lower-diversity assemblages which generally depend on replenishment from the marine realm. A good example of such an environment is the Gulf of Salwah which, in comparison to the rest of the Gulf combines a higher salinity with a relatively lower biological diversity (Apel & Türkay 1999). A broad scale of littoral, vagile inshore and particularly immature fishes potentially occur. In discussing permanent tide pools of creek beds Basson et al. (1977) reported the young and partly grown individuals of the following species: *Acanthopagrus* sp., *Lebias dispar*, *Gerres oyena*, *Gerres* sp., *Hemirhamphus far*, *Liza subviridis*, Mugilidae gen. sp., *Nematalosa nasus*, Platycephalidae gen. sp., *Pseudorhombus* sp., *Sardinella* sp., *Terapon jarbua*, *Pomacanthus maculosus*. During a monitoring survey of nine khawrs (coastal lagoons) of varying salinity in the Dhofar province of Oman, Fouda (1995) reported 47 species, of which 18 were recognised as being immature. According to Evans et al. (1973), as with bony fishes, small sharks and rays are commonly observed in lagoons and are therefore found on inundated sabkha surfaces, brought in with the inflowing current. A stranded stingray was found by West (1997) at the seaward margin of the Umm Said Sabkha in Qatar.

The "restricted environment" - salinities of 50 to ca 70 ppt: Moderately hypersaline biotopes with a higher salinity than the adjacent ocean like tidal flats, tide pools, backwaters, mangrove swamps, or isolated lagoons. These happen to be periodically cut off from the sea, then experience severe evaporation; housing impoverished assemblages of largely marine origin. The fishes which are reported (MEPA/IUCN 1989) include *Lebias dispar*, *Argyrops spinifer*, *Gerres oyena*, *Sardinella sindensis*, *Epinephelus coioides*. Particularly the last species has been reported by BASSON et al. (1977) to be abundant even at salinities approaching 70 ppt.

The "highly restricted environment" - salinities greater than 70 ppt: Strongly hypersaline biotopes with salinities of up to more than 200 ppt commonly occur in isolated lagoons, ponds, salt lakes, and high tide pools. They are subject to frequent drought, housing virtually unknown communities of continental and marine origin. Although poor in species, sometimes abundant populations of photosynthetic cyanobacteria and other micro-algae are found. No species of fish are reported, except of undetermined healthy young (Basson et al. 1977), *Lebias dispar* and *Liza subviridis*.

The "freshwater/brackish environment" - salinities below ca 30 ppt: This category has not been considered by the above cited studies. Not all aquatic sabkha habitats are characterised by salinities above the level of the adjacent ocean. In certain cases freshwater of indigenous or anthropogenic origin may control the water chemistry (Fouda 1995). The young of several families of marine fishes are amphidromous; namely terapontids, lutjanids, sciaenids and gobiids are known to actively enter nearshore brackish and freshwater. In April 2000 the second author visited a freshwater/brackish outlet pool for the Ruwais Housing settlement in western Abu Dhabi region just east of Jebel Dhanna (N 24°7'42.4", E 52°40' 0.1"). The pool was situated about 3 km from the present coastline, had a storm drain on its seaward side and was surrounded by sabkha. The salinity was about 6 ppt where the waste freshwater entered the pool, but increased to about 20+ ppt at the seaward side close to the storm drain which connected to an area of inundated wet sabkha. It was found to be colonised by abundant *Terapon jarbua* of various sizes from 7 to ca 13 cm total length. This site is one of the few recorded locations on the Abu Dhabi coast where fishes have exploited a niche in what is largely a classic sabkha-like environment. Also the glassfish *Ambassis gymnocephalus* is known to typically inhabit brackish inlets and estuaries. It has been recorded from Qurm Creek near Muscat, Oman (Randall 1995). Introduced *Tilapia*, *Oreochromis* or *Poecilia* species have been observed to flourish under hypo and hypersaline conditions. It is possible that these species occur elsewhere in sabkha-related fresh or brackish water habitats.

If freshwater courses discharge through sabkha environments, especially after periods of strong precipitation, it is possible that even primary freshwater fishes occur. The largest marsh area in the southern part of Iraq, the Hor al Hammer, is a freshwater environment proper. The composition of its fish assemblages was known to be nearly similar to that of the rivers Euphrates and Tigris, which is dominated by the freshwater family Cyprinidae. Khor al Zubair is a Northwest extension of the Gulf, housing a fish community of marine origin. Owing to a recently built channel, the Schatt al Basrah, which connects it to Hor al Hammar the fish communities are now reported to mix (Al-Hassan & Muhsin 1986). Several freshwater fishes e.g. *Barbus luteus* (Heckel, 1843) and *Heteropneustes fossilis* have been recorded from Khor al Zubair, while in a reverse process marine species have also invaded the freshwater of the inland marsh area. Only in a few of Arabia's wadis does open water reach lower altitudes. Several populations of *Garra*, *Cyprinion* and *Lebias* are known to occur in streams of the Oman mountains which drain towards the opposite direction into the Rub'al Khali and an area of inland salt marshes. Likewise, these species are known to occur in streams that drain over relatively short distances towards coastal khawrs (Banister & Clarke 1977, Fouda 1995, Feulner 1998).

Food & interrelationships

Beside physical factors and habitat availability, determined by the mere presence or absence of water referred to above, biological factors like the availability of food and nutrients, inter and intraspecific competition, and prey-predator interrelationships may well exist to control the diversity and abundance of sabkha fish communities. The diets of intertidal fishes of the tropics are poorly known (Norton & Cook 1999). Even less is known about the diets of the fish assemblages associated with mangroves and salt marshes, in spite of the large coastal areas covered by these ecosystems. A notable exception are the mudskippers (Barak et al. 1994, Clayton 1993) and *Leiognathus decorus* (Wright 1989) from the Gulf.

The trophic capacity of a biotope is determined by its primary production, intrinsic food web and productivity imported from adjacent aquatic and terrestrial biotopes. The salt marshes e.g. of the Pacific and Atlantic coast of America are very productive (Moyle & Cech 1982). Although less is known about the productivity of the salt marshes of Arabia, it is evident that their productivity is high as well. Some seaward sabkhat are believed to be the most productive ecosystems in the Gulf. Microscopic Cyanophyta forming extensive blue-green algal mats and diatoms are a source of excess consumable organic matter. Beside the indigenous primary productivity, lagoonal, mangal or mudflat biotopes which connect to sabkhat are thought to export substantial productivity into wet sabkhat. Macro-algae and seagrass detritus is washed into sabkhat, markedly enriching the nutrient content. Mangal, in particular, represents a very productive habitat of coastal wetlands in the area (Por et al. 1977, Price et al. 1987). Beyond the primary productivity rendered by the mangrove trees themselves, their pneumato-phores and stems provide solid substrate for rich communities of epiphytic organisms like macro and microscopic algae, bryozoans and sponges. A rich mix of macroinvertebrates, especially of detrivores and herbivores, lives associated with these communities. The abundant food organisms and the shelter provided by the mangrove thickets support juveniles of various groups of fish (Khalil 1994). Mudflats support vast numbers of small, especially burrowing animals, including crabs, gastropods, ostracods, nematodes, flatworms, copepods and annelid worms, biomass which is partly exported to sabkhat. The limited habitability of the semi-aquatic habitats and the extreme environmental premises pose major constraints to the productivity of macroscopic aquatic plants e.g. turf or macro-algae of the various phyla, or seagrasses. Higher vascular plants occupy the low mudbanks and the lower marsh adjacent to semi-aquatic sabkha habitats. A distinct zonation exists recognising community types of emergent, halophile macrophytes like grasses, herbs, and shrubs (Halwagy 1986, Jones 1986). These are considered the major source of productivity in salt marshes.

The high productivity of restricted ecosystems is often markedly contrasted by the comparatively low biological diversity. The excess organic matter of sabkhat is not directly consumed by a diverse community of higher trophic categories like fishes, but by-passed through a detrital food chain (Moyle & Cech 1982, Norton & Cook 1999) to a rather limited number of species. Despite the general environmental disadvantages, at least for a small number of fishes, the search for food is successful enough to balance the high energy costs expended in the tidal movements and in maintaining a physiological equilibrium under the harsh conditions.

Herbivores, grazing on diatoms and cyanobacterial mats of salt marshes and mudflats (*Boleophthalmus*) and omnivores (*Lebias*, *Terapon*, *Leiognathus*, *Gerres*, *Liza*, *Scartelaos*), which opportunistically ingest detrital matter, diatoms, micro-algae, and invertebrates like annelid worms, copepods, ostracods, and small crabs (for sabkha arthropods see Hogarth & Tigar, this volume) represent the majority of the species in consideration. Because there is little hard substrate present, the food of this group of fishes are mainly small items found somehow suspended (plankton), and adherent (cyanobacterial mats) or buried into the sediment (infauna). Beyond indigenous planctonic production planctivorous species like herrings, atherinids, and halfbeaks certainly feed on oceanic plankton imported with the tides. Not only zooplankton but also algal and detrital drift make up substantial proportions of the food of these fishes (Parrish 1989, Phillips, this volume).

Few species are predators (*Epinephelus*, *Argyrops*, *Periophthalmus*) preying upon other fishes (piscivores), on epifaunal macroinvertebrates like gastropods and crabs, and on shrimps. Where aquatic or semi-aquatic insects like odonata, coleoptera, diptera, and hemiptera inhabit sabkhat they are undoubtedly preyed upon on occasion. The Arabian pupfish *Lebias dispar* and terapontids take insects e.g. those living above and below the meniscus like halotolerant mosquito and chironomid larvae, pond striders (Hemiptera: Gerromorpha), or whirligig beetles (Gyrinidae). It is possible that terrestrial arthropods which actively enter into amphibious habitats like arachnids, or tenebrionid, carabid, and cicindelid beetles have prey-predator encounters with amphibious sabkha fishes to some extent. Finally, accidentally dislocated e.g. wind-blown terrestrial insects no doubt represent another source of food for sabkha fishes. For comprehensive treatises of the various aspects of intertidal fish biology in general the reader is referred to Horn et al. (1999).

DISCUSSION

The fish communities of sabkha environments have attracted very little attention by researchers in the past. The present review suggests that sabkha fish are more in number of species and individuals, hence of greater ecological importance than previously expected. Considering the fruitful studies of salt marshes accomplished in temperate and boreal regions the marshes of the Arabian Peninsula Region deserve a serious research attempt. The suite of species that will be recognised in future field work will depend on the actual physiographic delimitations set to define what is a sabkha habitat at a given study site.

The fact that fish species exploit sabkhat has possibly to be referred to niche displacement and predator avoidance. The disadvantages exerted by the harsh environmental conditions are apparently outweighed, at least for a selection of preadapted species, by a comparatively comfortable situation as far as competition for food and space, and predation are concerned. It has to be expected that sabkha fishes represent a food source for top predators like coastal birds. No data, however, are available. Observations of e.g. cormorants and terns, including studies of stomach contents shall potentially reveal interesting insights. In essence the interrelationships of sabkha fishes with other organisms largely remain to be studied.

As to what extent sabkha aquifers are used by fishes for spawning and as nursery grounds is not yet clear. The important role of mangal, lagoonal and estuarine biotopes in the avoidance of brood predation and as feeding grounds, rather than simply as spawning areas proper, have been demonstrated in a wealth of literature. It is desirable to study whether wet sabkhat have a potential to retain and sustain the planctonic young of coastal species, thereby supporting the replenishment last but not least of economically important species.

RECOMMENDATIONS

As very little is presently known about sabkha fishes it is desirable to initiate a research program specifically on the community composition and ecology of sabkha fishes, and the biotopes and biota they are associated with. The following research topics are considered to be of pivotal interest:

1. Mapping and classifying the sabkha habitats and biotopes: The positions and the extent of sabkhat around the Arabian peninsula should be mapped using Satellite Imagery. Bioinventory and habitat surveys within selected representative salt marsh areas shall be conducted to assess the different habitat and biotope types present and to identify their associated biota. The spectral reflectance at these ground-truthing sites could then be used to conduct a habitat and biotope classification of the sabkhat of the Arabian region by Satellite Image Processing. The data need to be stored into a customised GIS database.
2. Fish community composition: In selected sabkha-related habitats detailed qualitative surveys shall be conducted to study the species composition of the fish assemblages. Fishing and visual estimation techniques will have to be employed to collect time-series data on species abundances and community composition. It is crucial that the sampling sites represent the different habitat and biotope types.
3. Migration and replenishment: The research program should address the question where the populations of the different species do come from, for how long they stay, and when they leave sabkha habitats. Size-class data collected in tidal creeks and drainage channels of sabkhat, as well as in neighbouring coastal habitats, will elucidate the extent of fish migrations and the population structure of the species involved, hence patterns of replenishment. Different tidal levels,

different seasons and different sites throughout the Arabian region should be covered to assess the tidal, temporal and spatial variation.

4. Fisheries: Intertidal fishing is common throughout the area. Fishing activities within sabkha-related habitats like ponds, creeks and lagoons, as well as those which target areas in close proximity to sabkhat, shall be assessed. A comparison of catch data with those of the fish community, as well as migration studies will contribute towards answering the question whether the populations of species which are targeted in artisanal fisheries are replenished from adjacent, inundated sabkhat.

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